2.5   PARTITIONING THE NET CO_2 FLUX OF A DECIDUOUS FOREST INTO
RESPIRATION AND ASSIMILATION USING STABLE CARBON ISOTOPES

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1.   Introduction

Partitioning net CO_2 fluxes into their components, such as assimilation and respiration, and understanding the underlying mechanisms within ecosystems is essential for predicting future responses and feedbacks of ecosystems to a changing climate. Stable isotopes of atmospheric CO_2 (^{13}C and ^{18}O) offer the opportunity for an independent estimate of flux partitioning, complementary to eddy covariance measurements, providing additional, necessary information about carbon cycling in terrestrial ecosystems. Carbon isotopic discrimination (Δ) occurs during plant photosynthesis, when the lighter $^{12}CO_2$ is taken up by plants in preference to the heavier $^{13}CO_2$ leading to a depletion of ^{13}C in plant organic matter (Farquhar et al., 1989). This depleted carbon is released back to the atmosphere during plant respiration and microbial decomposition of organic matter. Due to temporal separation of carbon assimilation and respiration as well as due to compound specific substrate use in the soil, assimilation and respiration can carry different isotopic signatures allowing for partitioning the net CO_2 flux into its components (Bowling et al., 2001; Ogee et al., 2003).

In this study we present based on theory developed by Bowling et al. (2001) the first data set so far, that used stable carbon isotopes to partition net CO_2 fluxes over an extended period of three weeks providing the opportunity to study the relationship of assimilation to respiration during changing climatic conditions.

2.   Theory

The approach to separate the daytime net CO_2 flux (F) into assimilation (F_A) and respiration (F_R) is based on differences in the isotopic signatures of assimilation ($\delta^{13}C_a$-Δ) and respiration ($\delta^{13}C_R$). The ^{13}C isotope provides an additional constraint for the CO_2 exchange mass balance:

$$F = F_A + F_R \qquad (1)$$

$$F_\delta = (\delta^{13}C_a - \Delta)F_A + \delta^{13}C_R F_R \qquad (2)$$

where $\delta^{13}C_a$ is the isotopic signature of atmospheric CO_2 (‰) and Δ is canopy discrimination (‰). F is calculated from eddy covariance measurements and a

vertical profile of CO_2 mixing ratios (*Knohl et al.,* 2003). F_δ, the so-called isoflux, is calculated using the Eddy covariance/flask (EC/flask) technique by *Bowling et al.* (1999). The isotopic signature of ecosystem respiration ($\delta^{13}C_R$) is derived in our study from nighttime Keeling Plots (Keeling, 1958). Canopy discrimination (Δ) is calculated as (Farquhar et al., 1989):

$$\Delta = \overline{a} + (b - \overline{a})\frac{c_c}{c_a} \qquad (3)$$

where $\overline{a}$ is the fractionation during the transport of CO_2 from the canopy air space to the site of carboxylation (Ogee et al., 2003), b is the fractionation of the enzyme-catalyzed fixation of CO_2 (≈ 28‰), c_a the CO_2 mixing ratio (ppm) in air at measurement height, and c_c is the CO_2 mixing ratio (ppm) at the site of carboxylation. The CO_2 mixing ratio at the site of carboxylation (c_c) can be derived from the relationship of assimilation (F_A) and canopy conductance (g_c) as:

$$-F_A = g_c \cdot (c_a - c_c) \qquad (4)$$

Canopy conductance (g_c, mol m^{-2} s^{-1}) is calculated from the Penman-Monteith equation.

3.   Site and Methods

The study was conducted at the uneven-aged, unmanaged mixed beech forest at the Hainich tower site within the "Hainich National Park" in Central Germany (51°04'46'' N, 10°27'08'' E, 440 m a.s.l.). Maximum tree height varies between 30 and 35 m, with a maximum leaf area index of 4.8 m^2 m^{-2}, trees are up to 250 years old.

Carbon dioxide fluxes, using the eddy covariance technique, and meteorological variables were continuously measured at a height of 43.5 m since September 1999 (Knohl et al., 2003). Canopy air samples for stable isotope analysis were samples in vertical profiles on 13 days and 12 nights in 2002 (07/29/02 to 08/19/02). Stable carbon isotope ratios were measured using a continuous-flow isotope ratio mass spectrometer (IRMS) and Gasbench II (Finnigan MAT DeltaPlus XL, Bremen, Germany), equipped with a CTC PAL-80 autosampler (CTC Analytics AG, Zwingen, Switzerland).

4.   Results and Discussion

Canopy conductance as well as canopy discrimination showed large variation from day to day

(Figure 1a). Canopy discrimination was clearly higher during a rainy period (period I, 16 to 18 ‰) compared to those during sunny period (period II, 14 to 16‰). The isotopic signature of assimilation as calculated from $\delta^{13}C_a - \Delta$ was in most cases substantially higher from the isotopic signature of respiration ($\delta^{13}C_R$) derived from night-time Keeling Plot measurements, indicating that assimilation and respiration fluxes were isotopically not in balance (Figure1b). While differences between $\delta^{13}C_a - \Delta$ and $\delta^{13}C_R$ were up to 4‰ after the transition from a sunny to a rainy period (period I), they were between 3‰ and 5‰ after a transition from rainy to sunny conditions (period II).
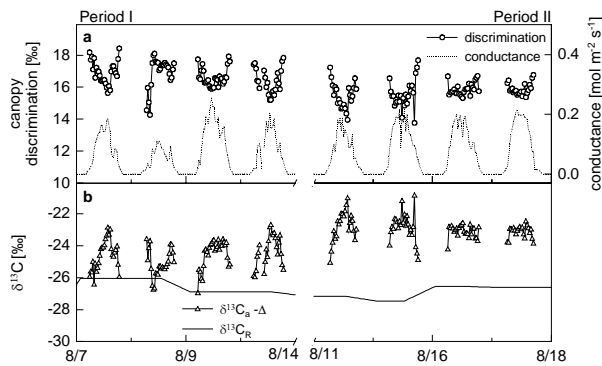
Figure 1: (a) Canopy discrimination and conductance as well as (b) $\delta^{13}C$ of assimilation ($\delta^{13}C_a - \Delta$) and respiration ($\delta^{13}C_R$) for two selected periods (I and II)

The smaller the differences between $\delta^{13}C_a - \Delta$ and $\delta^{13}C_R$, the larger the scatter in the calculated respiration flux (Figure 2, Period I vs. Period II). For times with optimal conditions for flux partitioning, a strong diurnal cycle in respiration was found (Period 2) indicating the reliability of the method.
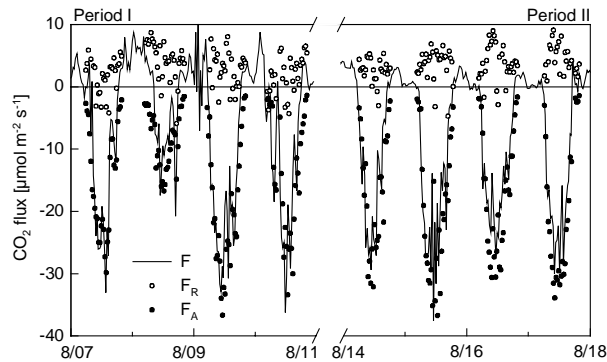
Figure 2: Net CO_2 flux (F) partitioned into assimilation (F_A) and respiration (F_R) for two periods (I and II)

The relationship of respiration to assimilation flux (F_R/F_A) proved to be highly variable over just a three-week period (Figure 3). Dependent on the environmental conditions, respiration accounted between 15% and 35% to assimilation. Interestingly, during days with low temperatures, a smaller proportion of assimilation was respired back to the atmosphere than during days with higher temperatures. As temperature increased, a larger amount of daily carbon assimilation was again lost to the atmosphere via respiration. If true also for other times of the year and other ecosystems, this would mean higher carbon uptake efficiency during days with low temperature compared to days with higher temperatures. Depending on acclimation effects, this temperature sensitivity will have pronounced impacts on the carbon budgets of these ecosystems, under current and under future climates.
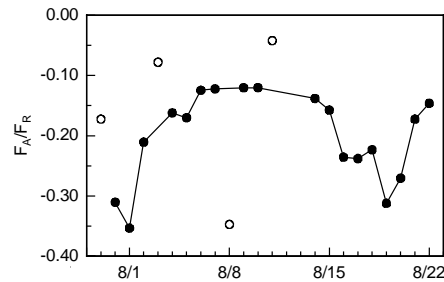
Figure 3: Temporal dynamics in the ratio of daily averages of respiration (F_R) to daily averages of assimilation (F_A). Data with low canopy conductance ($g_c < 0.12$ mol m^{-2} s^{-1}) are marked in open circles.

5. References

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